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Tests of Concrete &

Reinforced Concrete Wall Footings

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TESTS OF CONCRETE AND REINFORCED CONCRETE WALL FOOTINGS

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

CHARLES EMERY BRESSLER, JR. and NELS REUBEN HJORT

ENTITLED TESTS OF CONCRETE AND REINFORCED CONCRETE WALL FOOTINGS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

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INTRODUCTION

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Article 1, Preliminary.

Very little reliable information has been obtained on the subject of Wall Footing. This investigation is a continuation of Brand & Bushnell's Thesis of 1908, and its purpose is to determine safe working stresses which may be used in designing footings with or without reinforcement. The tests were made with the intention of approaching as nearly as possible to actual conditions.

Article 2, Scope of Tests.

(a) Forty-two footings were tested. Of these, eight were of plain concrete, eighteen with longitudinal reinforcement and sixteen with both longitudinal and web reinforcement. The proportions in the plain concrete footings varied from 1-1 1/2-3 to 1-3-6. Two pieces of each mixture were tested and the results compared. The footings with reinforcement were all made of 1-2 1/2-5 concrete. The percent of reinforcement varied from 0.55% to 1.53%. Two pieces were made and tested for each percent and method of reinforcing. The results were then compared and the conclusions drawn. All tests were made at about the age of sixty days.

(b) Notation.

The following notation will be used and is the same as that used in Bulletin No. 29, University of Illinois Experiment Station:

b = breadth of footing.

d = distance from the compression face to the center of metal reinforcement.

A = area of cross section of longitudinal reinforcement.

p = A/bd = ratio of area of metal reinforcement to area of concrete above center of reinforcement.

Notation (cont'd.)

o = circumference or periphery of one reinforcing bar.

m = number of reinforcing bars.

E_s = modulus of elasticity of steel.

E_c = initial modulus of elasticity of concrete in compression.

n = E_s/E_c = ratio of two moduli.

f = tensile stress per unit of area in metal reinforcement.

d' = distance from center of reinforcement to center of gravity of compressive stresses.

j = ratio d' to d.   d' = jd.

M = resisting moment at the given section.

S = horizontal tensile stress per unit of area in the extreme fiber of the concrete.

u = Bond stress per unit of area on the surface of the reinforcing bars.

v = Vertical shearing stress and horizontal shearing stress per unit of area in the concrete.

h = depth of plain footings which was eleven inches in all cases.

Article 3, Theory and Available Data.

(1) Classification of Stresses.

The different kinds of stresses which must be taken into account in the design of reinforced concrete wall footings are the same as those which occur in beams and may be classified as follows:

(a) Tension in the longitudinal reinforcement.

(b) Compression in upper fibers of concrete.

(c) Diagonal tension.

(d) Bond stresses, or stresses due to the tendency of the reinforcing bars to slip.

Failures by tension in the longitudinal reinforcement occurred

in the footings containing a percent of reinforcement toolow to develop the diagonal tension or bond stresses high enough for failure. In this series of tests no failures were obtained by compression of the concrete, the test pieces failing by tension in steel, diagonal tension or bond before the full compressive strength of the concrete was developed.

(2) Formulas used.

In calculating the stress in the longitudinal reinforcement the formula $M = Afjd$ was used, the notation being as given. Although the value of j varies from 0.83 to 0.87 for the range of percentages here used the constant value, $j = 0.87$ was used in the calculation.

The tensile stress in the lower fiber of the plain concrete was calculated from the flexure formula $M = SI/c$ where S is the stress in the lower fiber, I the moment of inertia of the section about the neutral axis and c is equal to h/2.

In the reinforced footings the vertical shearing stress was obtained from the formula $v = V/.87bd$ where V is the total vertical shear at the point and v is the vertical shearing stress in lb. per sq. in.

The bond stresses were obtained by the formula $u = V/.87mod$ as found in Bulletin No. 29, University of Illinois Experiment Station. Again V is the total vertical shear at the point and the rest of the notation is as given.

The above mentioned stresses were calculated for each footing and arranged in tables with other data, for convenience of reference.

Article 4.

Materials, Test Pieces and Method of Testing.

(1) Materials.

All materials used were bought, or supplied by manufacturers of the Middle West. The round steel rods were furnished by the Illinois Steel Company of Chicago. The corrugated rods were supplied by the Corrugated Bar Company of St Louis.

Sand. The sand was clean, sharp, well graded and of good quality from Attica Indiana. One cubic foot weighs approximately 100 Lbs. See Table No. 1 for mechanical analysis.

Stone. The stone used was a good quality of crushed lime stone from the quarry near Kankakee, Illinois. It was ordered screened through a one inch and over a quarter inch sieve. It contains about 48.5 percent voids. Table No. 2 shows mechanical analysis. It weighed about 83 lb. per cubic foot.

Cement. Chicago AA Portland Cement was used. Tensile strength at different ages and various proportions are as given in Table No. 3. Table No. 4 gives fineness tests of cement.

Concrete. The concrete was mixed by men accustomed to the work. Measurements were made by loose volumes and checked by weighing. Care was taken in the mixing to make the concrete of a uniform consistency. The sand and cement were first mixed dry. The stone was then added and the mass thoroughly mixed. Water was then added and the concrete well mixed.

Steel. Two kinds of reinforcing bars were used, plain round rods of different diameters and one half inch square corrugated bars, new style. The plain round rods were of mild open hearth steel with an elastic limit of about 40,000 lb. per sq. in. and the corrugated bars were of high steel with an elastic limit of about 56,000 lb. per sq. in. For tests on steel see Table No. 5.

Table No. 1

Analysis of Sand.

Sieve No.	Separation Size Inches	Per Cent Passing.
5	.174	94.3
10	.091	75.5
18	.043	53.4
30	.027	32.1
40	.019	18.5
50	.013	6.2
74	.009	3.3
150		.7

Table No. 2.

Analysis of Stone.

Diameter of Mesh. Inches	Per Cent Passing.
1"	100.0
$\frac{3}{4}$	90.2
$\frac{1}{2}$	59.8
$\frac{3}{8}$	34.5
$\frac{1}{3}$	17.2
$\frac{1}{5}$	3.1
$\frac{1}{10}$	1.7

(2) Test Pieces.

The footings tested had a width of 12 inches, and a total depth of 11 inches. The depth to the center of reinforcement was 10 inches. Except for No. 1665 and 1666, the seven foot pieces, all the footings were five feet long. The longitudinal reinforcing bars were four feet six inches long. When turned up bars were used they were bent up at points three inches and nine inches from the edge of the pier. In the pieces where stirrups were used they were placed at distances 2, 5, 9 and 15 inches from edge of stem. Figs. 1 and 2 show form of test pieces and arrangement of steel reinforcement.

(3) Making of Test Pieces.

The test pieces were made in wooden forms on the concrete floor of the Road Laboratory. A sheet of building paper was spread under the form;the latter were removed after seven days.

(4) Minor Test Pieces.

Plain concrete control beams 6 in. x 8 in. x 3 feet 4 inches and 6 inch cubes were made from the same batches as many of the footings. The cubes were tested in the 100,000 lb. Riehle Testing Machine. Table No. 6 gives the compressive strength of these cubes. The control beams were tested on a span of 3 feet and one-third point loading. The results of these tests are given in Table No. 7.

(5) Forms Used.

The forms were of 2 x 12 inch pine lumber dressed on both sides and held together by clamps. The pier was cast in a square wooden box placed on the form for the body of the footing. The pier was made of the same mixture as the footing.

Tests of Cement.

Table No. 3.

Number	7 Day	Test	28 Day	Test
	Neat	1-3	Neat	1-3
1	755	190	790	265
2	675	170	765	250
3	695	165	745	245
4	755	180	770	255
5	745	175		255
Mean	725	176	768	254

Cement - Chicago AA Portland.

Sand - Ottawa 20 - 30.

Number	7 Day	Test	28 Day	Test.
	Neat	1-3	Neat	1-3
1	690	260	815	305
2	695	225	800	310
3	710	225	800	315
4	725	225	805	300
5	760	225	815	300
Mean	716	232	807	306

Neat - 21% Water Used.

With Sand - 9% Water Used.

Number	7 Day	Test.	28 Day	Test.
	Neat	1-3	Neat	1-3
1	765	190	795	320
2	770	200	800	250
3	700	210	720	250
4	710	230	800	260
5	765	195	800	270
Mean.	742	205	783	270

(6) Storage.

The test pieces were left as made in the Road Laboratory and not moved until they were taken to the Materials Testing Laboratory to be tested. They were occasionally sprinkled with water to keep them from drying. The temperature ranged from 55° to 70° F.

(7) Machine Used.

The footings were tested in the 200,000 lb. Olsen Beam Testing Machine.

(8) Method of Testing.

In order to approximate the pressure of the soil on wall footings, the test pieces were placed on a bed of steel springs. The springs were 2 1/2 inches in diameter and 7 inches high. There were twenty sets of springs containing four each. The sets were spaced 3 inches center to center. The springs in each set were held in place 3 inches center to center by means of dowels just fitting the inside of the springs and screwed to an iron plate on which the footing rested directly. In the case of numbers 1665 and 1666 which were 7 feet long the sets were spaced four inches center to center.

After the test piece was in place and the springs arranged under it, the beam of the machine was balanced, the weight of the footing not being considered as part of the breaking load. Increments of 20,000 lb. were applied and deflections taken. The sides of the test pieces were watched for cracks and evidences of failure. First cracks appeared at from 40,000 to 80,000 lb. depending on the reinforcement, and continued until failure. The plain concrete footings failed suddenly and showed no preliminary signs of failure.

(9) Deflections.

When the first 2000 lb. had been applied the machine was

Table No. 4.

Fineness of Cement.

Quantity used - 1000 units.

Standard Mesh	Quantity Retained	Quantity Passing	Per Cent Retained	Per Cent Passing
No. 75	25	975	2.5	97.5
No. 100	72	928	7.2	92.8
No. 200	253	747	25.3	74.7

Void Tests of Sand.

Date	Weight of Box and Sand	Weight of Sand and Water	Net Weight of Water	Per Cent Voids
12-29-08	99.8	128.9	29.1	46.7
1-8-09	184.4	213.2	28.8	46.1
2-23-09	186.0	215.2	29.2	46.8

Void tests of Stone.

Date	Weight of Box and Stone	Weight of Stone and Water	Net Weight of Water	Per Cent Voids
12-29-08	83.0	114.3	31.3	50.0
1-8-09	172.6	201.2	28.6	45.8
2-23-09	162.5	193.5	31.6	49.7

stopped, and marks placed on the ends, at the quarter points, and at the middle of the footing, 11 inches above the bed of the machine as a means of obtaining deflections. After each increment was applied the distance to these marks was measured and subtracted from 11 inches to give the deflection of the point. These deflections were uniform and proportional to the load applied up to about 60,000 lb. in the reinforced footings. The deflections were used to determine the load at failure as indicated by the break in the former due to the bending in the test piece.

Article 5.

Notes on Tests and Failures.

In order to more clearly explain the method of failure of the test pieces, detail descriptions of the failure of each are given below:

Footings with Longitudinal Reinforcement.

No. 1631. Six 3/8-in. plain round rods, 0.55%. At 40,000 lb. a crack appeared six inches to the left of the pier and extended diagonally up toward the pier. Another crack appeared 2 1/2 inches inside of the right edge of the pier and extended vertically six inches. As the load increased the cracks opened up and at 75,000 lb. failure occurred by tension in the steel. As the test piece deflected considerably toward the end, the load was not uniformly distributed. From the deflections it was determined that the true failure occured at 55,000 lb. and this load was used in the calculations.

No. 1632. Reinforcement same as in No. 1631. At 55,000 lb. a crack appeared under each edge of the pier and extended almost vertically. Failure occurred at 78,000 lb. by tension in the steel but here also on account of the bending the maximum load used in the calculations was 60,000 lb.

No. 1633. Five 1/2-in. plain round rods, 0.82%. At 43,000 lb a crack appeared 2 1/2 in. to the left of the pier and extended almost vertically. Failure occurred at 78,000 lb. by tension in the steel and possibly bond. The failure was slow.

No. 1634. Reinforcement same as in No. 1633. At 40,000 lb. a crack formed on each side of the pier, 2 1/2 in. from it and extended almost vertically. The failure occurred at 73,000 lb. by slipping of the bar. The failure was slow.

No. 1635. Four 5/8-in. plain round rods, 0.98%. In this test no cracks were noticed before failure which occurred suddenly at 55,000 lb. The failure was by bond.

No. 1636. Reinforcement same as in No. 1635. At 80,000 lb. diagonal cracks appeared 7 in. on each side of and extending toward the pier. The piece failed at 89,500 lb. by diagonal tension, bond and tension in steel probably imminent. The failure was slow. In the calculations 80,000 lb. was taken as a maximum laod.

No. 1641. Five 5/8-in. plain round rods, 1.29%. At 60,000 lb. a diagonal crack appeared 7 in. to the left of the pier. Failure occurred suddenly at 92,000 lb. by bond and possibly diagonal tension. Examination of the end of the piece showed that the bars had slipped.

No. 1642. Reinforcement same as in No. 1641. At 60,000 lb. a diagonal crack appeared 5 in. to the left of the pier. Failure was slow and occurred at 80,000 lb. by bond and diagonal tension.

No. 1645. Six 5/8 in. plain round rods, 1.53%. At 60,000 lb. a crack was noticed 2 in. to the left of the pier and inclined slightly toward it. The footing failed suddenly at 80,000 lb. by bond and diagonal tension, the end of the test piece being thrown completely off the machine.

No. 1646. Reinforcement same as in No. 1645. At 60,000 lb. a crack appeared on each side of the pier, 8 in. from it and extending diagonally upward. Violent failure occured at 122,000 lb. by diagonal tension and bond. Maximum load used in calculation was 100,000 lb.

No. 1651. Four 1/2 in. square corrugated bars, high steel,

new style, 0.84%. At 60,000 lb. a diagonal crack was noticed 8 in. to the left of the pier. Violent failure took place at 80,000 lb. due to diagonal tension. The test piece tipped so that there was more load on the south end.

No. 1652. Reinforcement same as in No. 1651. At 60,000 lb. a diagonal crack opened 6 in. to the right of the pier. The piece failed violently at 116,000 lb. the north end being thrown off of the machine. Maximum load used in calculations was 85,000 lb.

No. 1655. Five bars same as in No. 1651, 1.04%. At 60,000 lb. a diagonal crack was noted 8 in. to the left of the pier. Failure occurred suddenly at 72,000 lb., the left end being thrown off the machine. The failure was by diagonal tension. The piece tipped and there was more load on the south end.

No. 1656. Reinforcement same as in No. 1655. At 60,000 lb. a diagonal crack appeared 6 in. to the left of pier. The piece failed violently at 108,000 lb. by diagonal tension. The maximum load used in calculations was 100,000 lb.

No. 1661. Six square corrugated bars, same as above, 1.25%. At 80,000 lb. a diagonal crack opened on each side of the pier and 8 in. from it. At 141,000 lb. the piece failed violently by diagonal tension. The maximum load used in calculations was 120,000 lb.

No. 1662. Reinforcement same as in No. 1661. At 80,000 lb. a diagonal crack appeared 8 1/2 in. to the left of the pier. Failure occurred suddenly by diagonal tension at 114,000 lb. The footing tipped and there was more load on the south end.

No. 1665. This footing was 7 ft. long, reinforcement same as in No. 1661. At 60,000 lb. a crack appeared on each side of the pier and 15 in. from it. Failure occurred suddenly at 84,500 lb.

by diagonal tension. There was more load on the south end.

No. 1666. Also 7 ft. long. Reinforcement same as in No. 1661. At. 55,000 lb. two diagonal cracks appeared, one 8 in. to the left of the pier and the other 2 in. to the right of the pier. The piece failed violently at 94,000 lb. by diagonal tension. The concrete below the reinforcement separated from the body of the footing.

Plain Concrete Footings.

These included all numbers between 1601 and 1616. These all failed in the same manner, there being no preliminary indications of failure. For loads at failure and comparison of different mixtures, see Table No. 8. Data and tests of footings with longitudinal reinforcement are given in Table No. 9.

Footings with Bent up Bars.

No. 1671. Five 1/2 in. plain round rods, one straight and four bent up at two points, 0.84%. At 70,000 lb. a vertical crack appeared just under the left edge of the pier. The piece failed slowly at 125,000 lb. by tension in the steel. The bending effect was considerable, the crack having opened up 1/4 in. at 100,000 lb. By the deflections it was determined that the failure really occurred at about 80,000 lb. and this was used in the calculations.

No. 1672. Reinforcement same as in No. 1671. At 60,000 lb. a crack appeared 2 in. to the right of the pier and inclined slightly toward it. On the left side a vertical crack showed just under the edge of the pier and another 2 in. to the left. These cracks opened up until at 100,000 lb. they extended to the top of the footing, and were 1/4 in. wide at the bottom. The load was run up to 144,000 lb. when failure occurred by tension in the steel, but because of

the extreme bending and unequal distribution of load the real failure was hardly above 80,000 lb. and this was used.

No. 1673. Five 5/8 in. round rods, one straight and four bent up at two points, 1.29%. This footing was first put on springs 3 in. by 12 in. placed 3 in. center to center. The load was applied up to 80,000 lb. when the springs bent and the piece thrown out of position. First cracks had appeared at 60,000 lb. one on each side of the pier and about 1 in. from it. The springs were then reset and the load run up to 98,000 lb. when the footing again swung out of position. The piece was then placed on the 2 1/2 in. by 7 in. springs as in other tests and the load run up to 134,000 lb. The springs at this load were practically closed and the cracks were 1/4 in. wide at the bottom. By the deflections it was determined that the failure was by bond probably after 98,000 lb. and this was the maximum load used in the calculations.

No. 1674. Reinforcement same as in No. 1673. At 60,000 lb. the first crack was noted just under the right edge of the pier and nearly vertical. The piece failed at 99,500 lb. by diagonal tension crack opening and causing slip of bars at final failure. The diagonal tension crack opened 8 in. to the left of the pier. The piece was examined and it was found that the turned up bars had slipped 1/2 in.

No. 1675. Six 5/8 in. plain round rods, two straight and four bent up at two points, 1.53%. At 80,000 lb. two diagonal cracks appeared on right 2 in. and 12 in. from pier. Failure occurred slowly at 135,000 lb., slipping of the bars allowing diagonal tension failure. The cracks at failure opened up 1/4 in. and the load was then taken off.

No. 1676. Reinforcement same as in No. 1675. At 75,000 lb. the first crack was noticed 4 in. to the left of the pier. The piece failed slowly by diagonal tension on a crack beginning 7 in. to the left of the pier. The diagonal tension failure also allowed bars to slip slightly. The load at failure was 99,000 lb.

No. 1681. Six ~~Five~~ 1/2 in. square corrugated bars, high steel, two straight and four bent up at two points, 1.25%. At 80,000 lb. first cracks appeared. The load was run up to 125,000 lb. six vertical cracks opening under pier and one slightly to the left of it. As the springs were practically closed the load was taken off and the piece tested on supports 4 ft. 4 in. apart. By this loading the footing failed at 60,000 lb. An examination showed that the bars had slipped. The maximum load used in calculations was 125,000 lb. as there was very little bending up to this point. The first cracks to open were probably tension cracks and the final failure was by bond.

No. 1682. Reinforcement same as in No. 1681. In this test the first cracks appeared at 80,000 lb., one 3 in. inside left edge of pier and one 4 in. outside and extending diagonally toward edge of pier. The inner crack was vertical. The load was run up to 200,000 lb. but the springs took the entire load from 160,000 to 200,000 lb. by direct compression. From the deflection the maximum load was determined to be not more than 140,000 lb. and this load was used in the calculations. The failure was by tension in the steel.

Footings with Stirrups.

No. 1685. Five 5/8 in. plain round rods, round vertical stirrups near stem, 1.25%. At 60,000 lb. a diagonal crack appeared

3 1/2 in. to right of pier. Just as the load was being applied the piece failed slowly by bond followed by diagonal tension. The load at failure was 61,500 lb.

No. 1686. Reinforcement same as in No. 1685. At 60,000 lb. a vertical crack appeared 1 in. inside right edge of pier. The piece failed suddenly at 82,000 lb. by bond. Examination showed that the bars had slipped 3/8 in.

No. 1687. Reinforcement same as in No. 1685, corrugated stirrups. At 40,000 lb. a vertical crack appeared 2 in. to the left of the pier. The failure occurred slowly at 80,000 lb. by slip of bar. The inner stirrup also slipped.

No. 1688. Reinforcement same as in No. 1687. At 60,000 lb. a crack appeared 1 1/2 in. to the right of pier and extending 1 in. inside of pier near top at failure. The failure was slow and by bond. The load at failure was 108,000 lb.

No. 1691. Six 1/2 in. square corrugated bars, high steel, round vertical stirrups near stem, 1.25%. At 48,000 lb. a crack appeared 2 in. to left of pier and inclined toward it. The piece failed slowly at 50,000 lb. by diagonal tension. Inner stirrups found to have slipped.

No. 1692. Reinforcement same as in No. 1691. At 61,000 lb. a vertical crack was noticed 1 in. to left of pier. The footing failed slowly at 120,000 lb. by diagonal tension and bond just as the deflections were about to be taken.

No. 1693. Reinforcement same as in No. 1691, corrugated stirrups near stem. At 80,000 lb. a crack appeared just under the left edge of the pier, extending slightly inward but almost vertical. The piece failed suddenly at 106,600 lb. by diagonal tension between

two stirrups.

No. 1694. Reinforcement same as in No. 1693. Two cracks were noted at 60,000 lb., 2 in. and 5 in. to left of pier and joining 5 1/2 in. above the base. (See Fig.) The failure occurred suddenly at 113,000 lb. on a crack 9 in. to the left of the pier. The failure was by diagonal tension and the bars and inner stirrup were found to have slipped.

Table No. 5.

Tests of Steel.

Reference No	Size. In.	Per Cent Elongation	Yield Point Pounds.	Yield Point Lb. per Sq. In.	Ultimate Strength Lb. per Sq. In.
1632	.375	31.0	4490	40700	48800
1634	.506	29.0	7930	39500	56400
1635	.496	24.5	8410	43600	65700
1641	.628	32.0	12000	38800	59700
1642	.627	30.5	11370	36700	51500
1646	.625	35.0	10475	34200	49000
1652	$\frac{1}{2}$"sq.corr.	13.0	14350	57400	95600
1666	.500	16.0	13300	53200	105200
1671	.500	34.0	6950	35400	46000
1686	.626	29.0	11510	37600	54600
1691	$\frac{1}{2}$"sq.corr.	16.7	14050	56200	100600
1692	.500	13.5	12500	50000	104000

Table No. 6.

Tests of Six Inch Cubes.

Number	Kind of Concrete	Age at Test Days	Max. Load Lb. per Sq. In.	Number	Kind of Concrete	Age at Test Days	Max. Load Lb. per sq. in.
1601	1-3-6	67	1250	1673	1-2½-5	62	1700
"	"	"	1480	"	"	63	1960
"	"	"	1460	"	"	63	1545
1611	1-2-4	68	1360	1681	1-2½-5	62	1700
"	"	"	1360	"	"	63	1960
"	"	"	1360	"	"	63	1545
1605	1-2½-5	69	1800	1685	1-2½-5	57	1300
"	"	"	1830	"	"	"	1300
"	"	"	1860	"	"	"	1280
1636	1-2½-5	69	1420	1693	1-2½-5	57	1300
"	"	"	1720	"	"	"	1300
"	"	"	1860	"	"	"	1280
1651	1-2½-5	68	1780	1631	1-2½-5	63	1195
"	"	"	1860	"	"	"	1255
"	"	"	1750	"	"	"	1070
1615	1-1½-3	68	2690	1633	1-2½-5	63	1195
"	"	"	2920	"	"	"	1255
"	"	"	2720	"	"	"	1070
1655	1-2½-5	61	1890	1634	1-2½-5	66	1240
"	"	"	1660	"	"	"	1370
"	"	"	1440	"	"	"	1255
1645	1-2½-5	61	1890	1687	1-2½-5	67	1660
"	"	"	1660	"	"	"	1515
"	"	"	1440	"	"	"	1545
1665	1-2½-5	73	1635	1606	1-2½-5	66	1240
"	"	"	1830	"	"	"	1370
"	"	78	2060	"	"	"	1255
1661	1-2½-5	72	1645	1694	1-2½-5	67	1660
"	"	73	1885	"	"	"	1515
"	"	73	1740	"	"	"	1545

Table No. 6.

Tests of Six Inch Cubes, (cont'd.)

Number	Kind of Concrete	Age of Test Days	Max. Load Lb. per sq. in.	Number	Kind of Concrete	Age of Test Days	Max. Load Lb. per sq. in.
1642	1-2½-5	60	1525	1652	1-2½-5	62	1150
"	"	"	1390	1662	1-2½-5	75	1665
"	"	"	1320	"	"	"	1830
1632	1-2½-5	60	1525	"	"	"	1580
"	"	"	1390	1688	1-2½-5	75	1665
"	"	"	1320	"	"	"	1830
1675	1-2½-5	69	1470	"	"	"	1580
"	"	"	1655	1612	1-2-4	75	1360
"	"	"	1490	"	"	"	1890
1671	1-2½-5	59	1260	"	"	"	1340
"	"	"	1215	1692	1-2½-5	60	1315
"	"	"	1230	"	"	"	1480
1641	1-2½-5	69	1470	"	"	"	1600
"	"	"	1655	1674	1-2½-5	60	1315
"	"	"	1490	"	"	"	1480
1646	1-2½-5	59	1260	"	"	"	1600
"	"	"	1215	1616	1-1½-3	70	2070
"	"	"	1230	"	"	"	2100
1682	1-2½-5	62	1460	"	"	"	2030
"	"	"	1440	1676	1-2½-5	55	1255
"	"	"	1150	"	"	"	1373
1672	1-2½-5	75	1360	"	"	"	1330
"	"	"	1890	1666	1-2½-5	55	1255
"	"	"	1340	"	"	"	1373
1652	1-2½-5	62	1460	"	"	"	1330
"	"	"	1440				

Table No. 7.

Tests of Plain Concrete Control Beams.

Number	Age. Days.	Load Pounds	Mixture	Mod. of Rupture Lb. per sq. in.
1601	69	2450	1-3-6	240
1602	80	2320	"	228
1605	67	3100	1-2½-5	301
1606	65	2740	"	267
1611	69	2800	1-2-4	273
1615	67	3900	1-1½-3	376
1631	56	2350	1-2½-5	231
1632	65	2910	"	283
1633	56	2350	"	231
1634	65	2740	"	267
1636	67	3340	"	323
1641	81	2810	"	274
1645	72	3530	"	341
1646	63	2580	"	252
1651	61	2670	"	260
1652	80	2760	"	269
1655	72	3530	"	341
1661	63	3150	"	306
1662	86	3360	"	325
1665	63	3150	"	306
1666	65	2610	"	255
1672	86	3250	"	315
1673	62	2980	"	290
1681	62	2980	"	290
1685	57	2980	"	290
1687	66	2960	"	288
1692	60	2310	"	227
1693	57	2980	"	290

Table No. 8.

Data and Tests of Plain Concrete Footings.

Footing No.	Age Days	Kind of Concrete	Cement Kind	Cement Per Cent	Maximum Applied Load Lbs.	Tension in Lower Fiber of Concrete Lbs. per sq. in.	Length of Footing Ft.
1601	62	1-3-6	AA	10.1	13000	258	5
1602	73	1-3-6	AA	10.7	14000	278	5
1605	64	1-2½-5	AA	13.5	20000	397	5
1606	63	1-2½-5	AA	12.3	11 000	218	5
1611	62	1-2-4	AA	14.6	16000	317	5
1612	69	1-2-4	AA	12.5	21 000	417	5
1615	65	1-1½-3	AA	20.5	16500	327	5
1616	67	1-1½-3	AA	18.7	17000	337	5

Table No. 9,

Data of Footings with Longitudinal Reinforcement.

Footing No.	Kind of Concrete	Cement		Reinforcement		Length Feet
		Kind	Per Cent	Description	Per Cent	
1631	1-2½-5	AA	12.2	6-⅜ in. plain round	0.55	5
1632	"	"	12.2	"	0.55	"
1633	"	"	12.2	5-½ in. plain round	0.82	"
1634	"	"	12.3	"	0.82	"
1635	"	"	12.3	6-½ in. plain round.	0.98	"
1636	"	"	11.6	"	0.98	"
1641	"	"	12.3	5-⅝ in. plain round.	1.28	"
1642	"	"	12.2	"	1.28	"
1645	"	"	12.2	6-⅝ in. plain round.	1.53	"
1646	"	"	11.5	"	1.53	"
1651	"	"	12.1	4-½ in. sq. corr. h.s.	0.84	"
1652	"	"	12.2	"	0.84	"
1655	"	"	12.2	5-½ in. sq. corr. h.s.	1.04	"
1656	"	"	12.4	"	1.04	"
1661	"	"	11.7	6-½ in. sq. corr. h.s.	1.25	"
1662	"	"	12.3	"	1.25	"
1665	"	"	12.3	6-½ in. sq. corr. h.s.	1.25	"
1666	"	"	12.7	"	1.25	"

Table No. 10.

Tests of Footings with Longitudinal Reinforcement.

Footing No.	Age Days	Load at First Crack Pounds	Maximum Applied Load Pounds	Stress in Longitudinal Reinforcement Lbs. per sq. in.	Vertical Shearing Stress Lbs. per sq. in.	Bond Stress Lbs. per Sq. in.	Reinforcement. Per Cent.	Manner of Failure
1631	63	40 000	55 000	46 000	212	355	.55	Tension in Steel
1632	64	55 000	60 000	50200	237	395	.55	Tension in Steel
1633	63	43 000	78000	43800	298	455	.82	Tension and possibly Bond.
1634	63	40000	73 000	41 000	278	430	.82	Bond Failure
1635	57	55000	55000	25800	211	323	.98	Bond Failure
1636	64	80000	80 000	37500	307	470	.98	D.T. Bond and Tension probably imminent.
1641	70	60000	92000	33 100	352	370	1.28	Bond + possibly Diagonal Tension
1642	64	60 000	80 000	28800	307	375	1.28	Do.
1645	59	60 000	80 000	24 100	307	310	1.53	Perhaps Bond + finally D.T.
1646	76	60000	100 000	30 100	383	390	1.53	D.T. + possibly Bond.
1651	65	60000	80 000	44 000	307	460	.84	D.T. Load mostly on South end.
1652	73	60 000	85 000	46800	325	490	.84	D.T.
1655	59	60000	72 000	31800	276	330	1.04	D.T. Load more on South End.
1656	67	60000	100000	44200	383	460	1.04	D.T.
1661	70	80000	120 000	44200	460	460	1.25	D.T.
1662	69	80000	114 000	42 000	437	435	1.25	D.T. Load more on South End.
1665	62	55 000	84 000	49 700	345	250	1.25	Do.
1666	58	55 000	94000	55 600	386	280	1.25	D.T.

Nos. 1665 and 1666 were 7ft long. All others were 5ft.

Table No. 11.

Data on Footings with Turned up Bars.

Footing No.	Kind of Concrete	Cement		Longitudinal Reinforcement.		
		Kind	Per Cent	Description	Per Cent	Disposition.
1671	1-2½-5	AA	11.5	5-½ in. round.	.82	1 straight.- 4 bent.
1672	"	AA	12.5	"	.82	"
1673	"	AA	12.1	5-⅝ in. round	1.28	1 straight- 4 bent.
1674	"	AA	13.0	"	1.28	"
1675	"	AA	12.3	6-⅝ in. round	1.53	2 straight.-4 bent
1676	"	AA	12.7	"	1.53	"
1681	"	AA	12.1	6-½ in. sq. corr. h.s.	1.25	2 straight- 4 bent
1682	"	AA	12.2	"	1.25	"

Table No. 12.

Tests of Footings with Turned up Bars.

Footing No.	Age Days	Load at First Crack Lb.	Maximum Applied Load Lb.	Stress in Longitudinal Reinforcement Lb. per Sq. In.	Vertical Shearing Stress Lb. per Sq. In.	Nominal Bond Stress Lb. per Sq. In.	Description of Failure.
1671	76	70 000	80 000	44800	307	470	Tension in Steel
1672	66	60 000	80 000	44800	307	470	Tension in Steel.
1673	60	60 000	98000	35200	375	458	Probably Bond Failure after 98000
1674	60	60 000	99500	35800	382	466	D.T. and finally failed by Bond.
1675	69	80000	135 000	40500	538	526	Bond. Slip of bars allowed D.T. Failure.
1676	58	75000	99000	29700	395	385	D.T. and possibly Bond. Bars found to have slipped
1681	60	80000	125000	46000	480	480	Tension cracks opened. Probably Bond Failure.
1682	73	80 000	140000	51500	580	537	Tension in Steel.

Table No. 13.

Data of Footings with Stirrups.

Footing No.	Kind of Concrete	Cement		Longitudinal Reinforcement			
		Kind	Per Cent	Description	Per Cent	Rods	Stirrups
1685	1-2½-5	AA	11.6	5-⅝ in round	1.25	5 straight	Round
1686	"	AA	12.4	"	1.25	"	"
1687	"	AA	12.8	"	1.25	"	Corr.
1688	"	AA	12.3	"	1.25	"	"
1691	"	AA	12.3	6-½ in. sq. corr.	1.25	6 straight	Round.
1692	"	AA	13.0	6-½ in. sq. corr.	1.25	"	"
1693	"	AA	11.6	"	1.25	"	Corr.
1694	"	AA	12.8	"	1.25	"	"

Table No. 14.

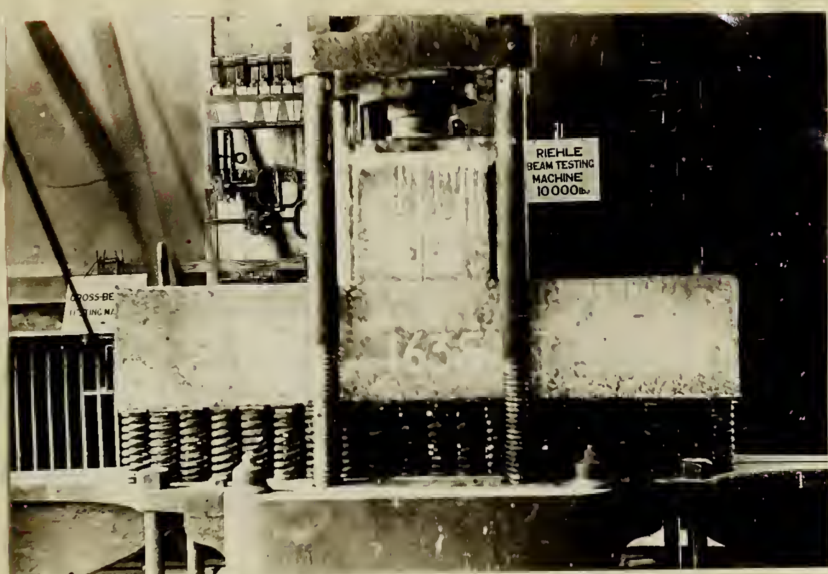
Tests of Footings with Stirrups.

Footing No.	Age Days	Load at First Crack Lb.	Maximum Applied Load Lb.	Stress in Longitudinal Reinforcement. Lb. per Sq. in.	Vertical Shearing Stress Lb. per Sq. In.	Bond Stress Lb. per Sq. In.	Manner of Failure.
1685	61	60000	61500	22600	236	288	Probably bond followed by D.T.
1686	67	60000	82000	30200	314	384	Bond Failure
1687	64	40000	80000	29500	306	374	Bars and inner stirrup slipped.
1688	69	60000	108000	38700	414	505	Bond Failure
1691	57	48000	50000	20400	213	213	Diagonal Tension
1692	60	61000	120000	44200	460	460	Diagonal Tension
1693	61	80000	106600	39200	408	408	D.T. Failure between 2 stirrups.
1694	64	60000	113000	41600	433	433	D.T. Bars and inner stirrup slipped.

Photograph of Footing before Test

Showing

Arrangement of Springs.



Article 6.

- D I S C U S S I O N -

In the plain concrete footings the strength was found to increase with the richness of the mixture up to 1 - 2 - 4. The strength of the two 1 - 1 1/2 - 3 pieces fell below the values obtained for the 1 - 2 - 4 mixture. This was probably due to defective mixing or placing. All the failures were by tension in the concrete. The values of the stresses in the extreme fiber at failure varied from 268 lb. per sq. in. in the 1 - 3 - 6 mixture to 367 lb. per sq. in. in the 1 - 2 - 4 mixture.

By the use of straight reinforcing bars the strength of the footings was increased from 400 to 800% over those without reinforcement. The strength was found to increase with the percent of reinforcement which varied from 0.55% to 1.53%. Most of the test pieces failed by diagonal tension or bond. The diagonal tension failures were usually violent, often throwing part of the footing off the weighing table of the machine. The bond failures were as a rule slow as were also the failures by tension in the steel. By the use of corrugated bars much higher strengths were obtained for the same percent of reinforcement, due to the greater resistance to slipping of the bars. These high bond stresses also increased the resistance to diagonal tension. The vertical shearing stresses developed ranged from 220 lb. per sq. in. for 0.55% reinforcement to 345 lb. per sq. in. for 1.25% reinforcement of plain round rods. For the corrugated bar reinforcement the vertical shearing stresses ranged from 316 lb. per sq. in. for 0.82% to 445 lb. per sq. in. for 1.25%. The bond stresses varied from 350 lb. per sq. in. to 475 lb. per sq. in.; the corrugated bars developing the higher

values. The pieces which failed by bond gave early signs of failure by almost vertical cracks like those caused by failure by tension in the steel.

The turned up bars increased the strength of the footing from 5 to 30% over those having only straight reinforcement. In this series of tests all the test pieces had four bars turned up and one or two straight. Reinforcing thus for diagonal tension caused failure in most cases by slipping of the bars.

Steel stirrups did not increase the strength of the test pieces and in some cases actually decreased it. This was probably due to defective placing of stirrups, some actually being visible on the side of the footing before the test was made. Although the stirrups did not strengthen the footing they seemed to act to prevent failure by diagonal tension, and most of the pieces failed by bond, although a few failures were obtained by diagonal tension.

Two footings 7 ft. long were tested having 1.25% square corrugated high steel bars and no web reinforcement. They failed by diagonal tension and developed 76% of the strength of the 5 ft. pieces similarly reinforced. No footings of this length containing stirrups were tested, but the stirrups would probably have been more effective for these pieces than for the shorter ones. This is born out by the fact that stirrups are very effective in beams which are usually longer than 5 ft.

In testing several of the stronger footings the springs closed at 130,000 lb. or above. When this happened the springs carried the load to the bed of the machine, causing no additional stress in the test piece except compression directly under the pier. The maximum load in these cases was determined from the

deflections and was usually less than the load at which the springs closed.

Only one mixture was used with the reinforced footings so the effect of the mixture on their strength cannot be determined from these tests.

Article 7.

-C O N C L U S I O N S.-

On account of the variability in mixing and placing concrete, a high factor of safety should be used in the design of plain concrete footings. This variability is shown by the 1 - 1 1/2 - 3 concrete developing loss strength than the 1 - 2 - 4 mixture. Using a factor of safety of 6 the safe tensile stress in the lower fiber of the concrete would be 45 lb. per sq. in. for a 1 - 3 - 6 mixture and 60 lb. per sq. in. for a 1 - 2 - 4 mixture.

Corrugated bars have a decided advantage over plain round rods and effect a saving of steel. The cost of the former is higher than that of the latter and it is doubtful if there is any saving in cost. The effectiveness of corrugated bar is due to their high resistance to bond and diagonal tension failures.

Turned up bars are a very effective reinforcement to resist diagonal tension. The best arrangement of reinforcement is to have turned up bars and square corrugated high steel bars. Thus high tensile bond and diagonal tension stresses are developed at the same time. This is shown by footings Nos. 1681 and 1682 which carried loads of 125,000 and 140,000 lb. respectively without appreciable bending. The high values of 51,500 lb. per sq. in. in the steel, 580 lb. per sq. in. vertical shearing stress and 537 lb. per sq. in. bond stress were developed in No. 1682.

Steel stirrups are not to be recommended in a footing of the form and dimensions used in this series of tests. As stated above they would probably be effective in footings of greater length. Although they act to prevent diagonal tension failures they are not as effective for this purpose as turned up corrugated bars.

Increasing the length of the footing decreases the strength of the piece for the same per cent of reinforcement. The comparison is not strictly accurate as a different spacing of the springs was used in the longer test pieces.

From this series of tests the following values are safe working stresses to be used in the design of footings:

Tension in plain concrete, extreme fiber, 1 - 3 - 6 ....
..... 45 lb. per sq. in.

Tension in plain concrete, extreme fiber, 1 - 2 - 4 ....
..... 60 lb. per sq. in.

Vertical shearing stress at edge of pier, reinforced footings
.... 100 lb. per sq. in.

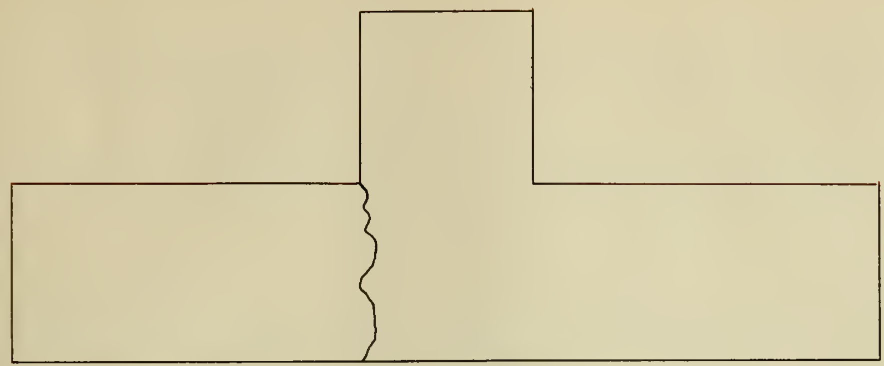
Bond stress at edge of pier, round rods ....
.... 100 lb. per sq. in.

Bond stress at edge of pier, corrugated bars ....
.... 150 lb. per sq. in.

Tension in steel, medium .... 16,000 lb. per sq. in.

Tension in steel, high elastic limit ....
.... 20,000 lb. per sq. in.

Compression in concrete .... 400 lb. per sq. in.



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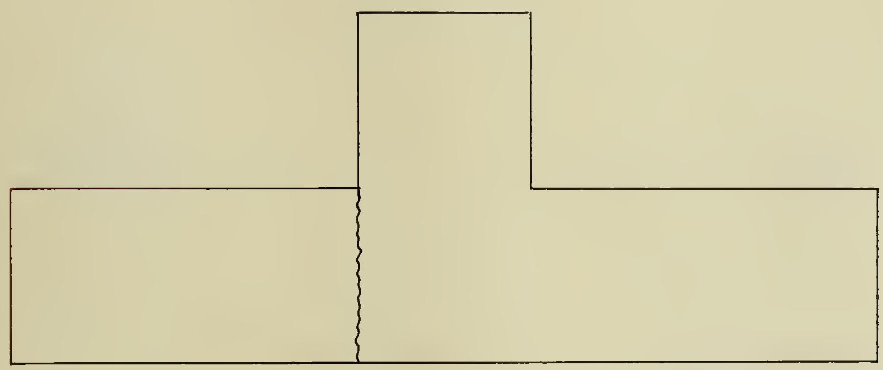

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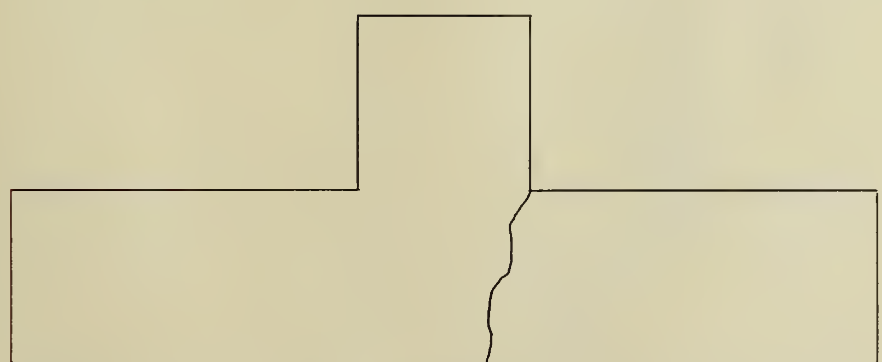

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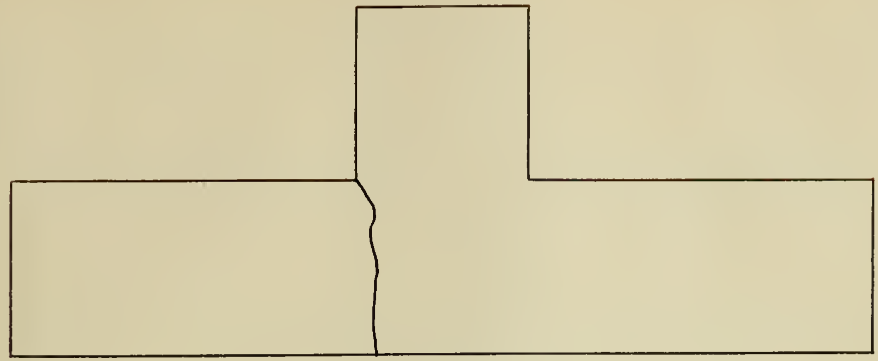

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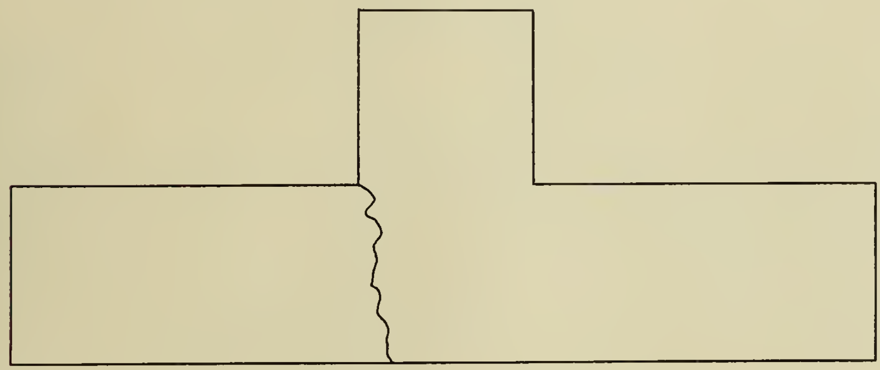

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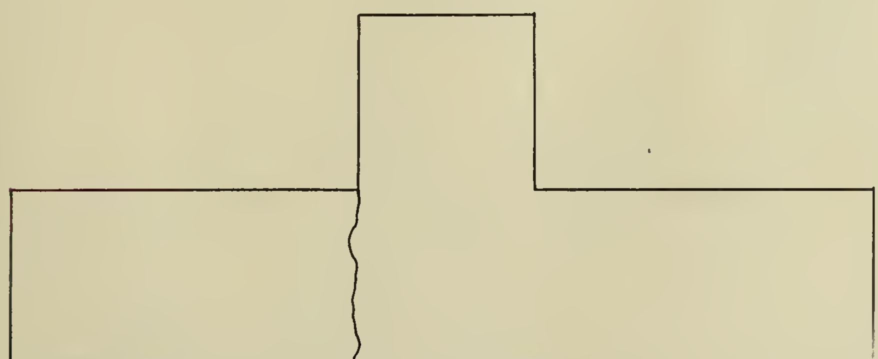

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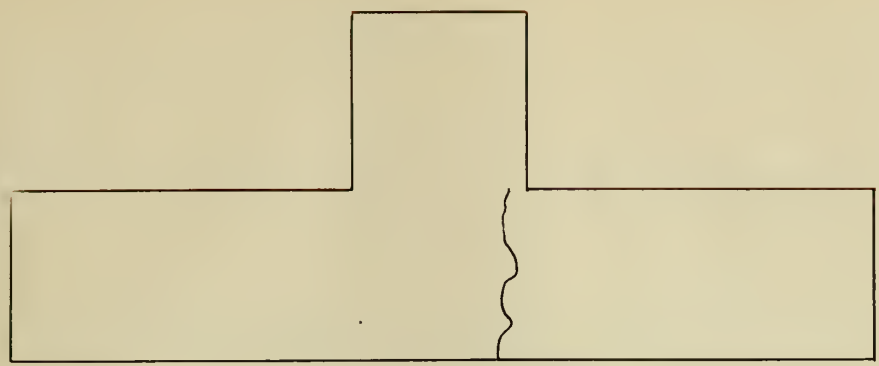

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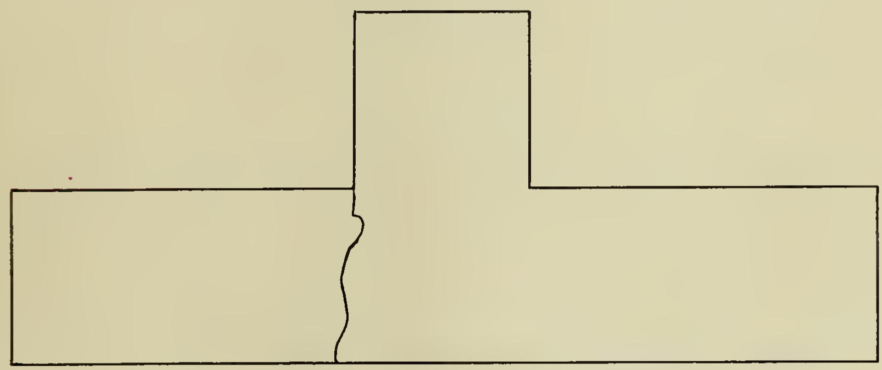

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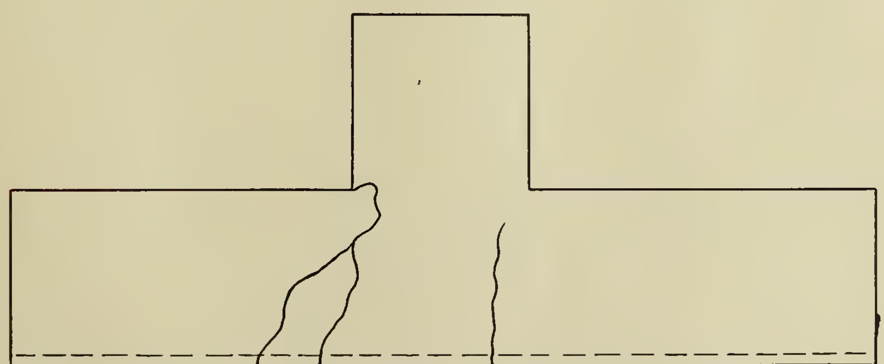

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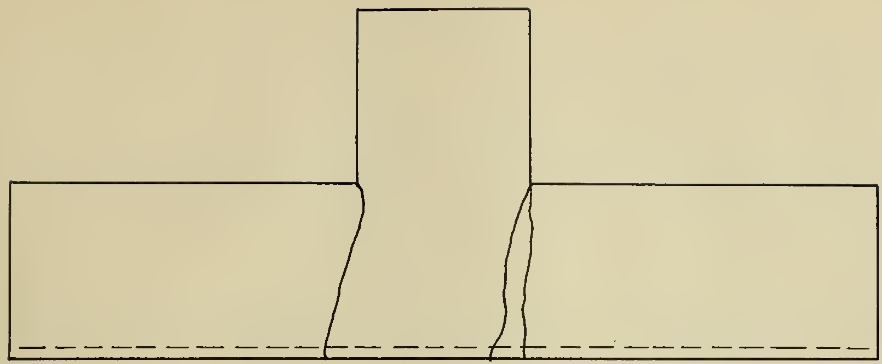

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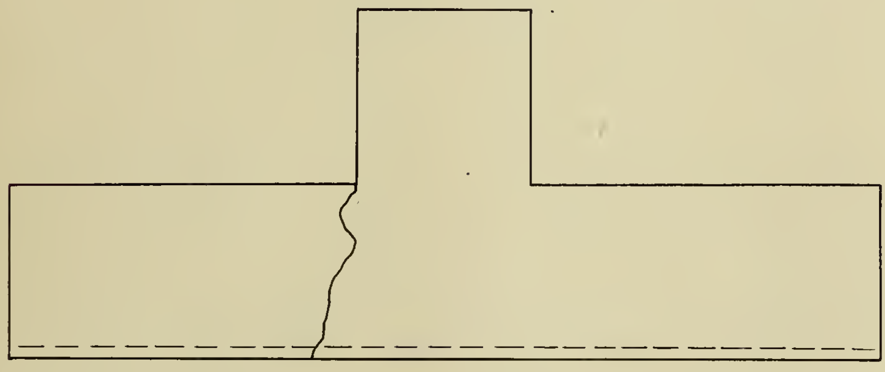

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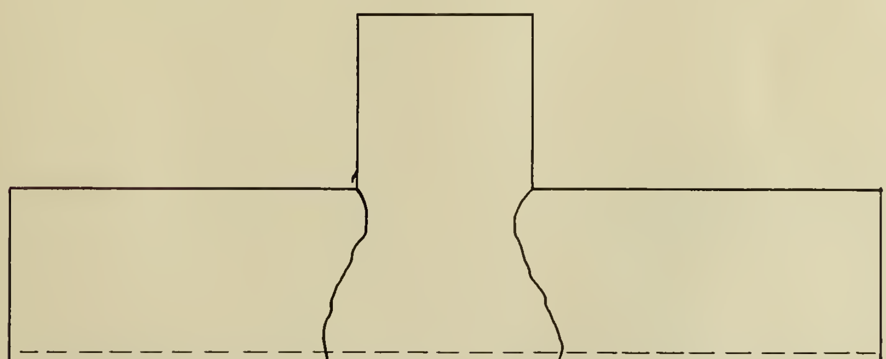

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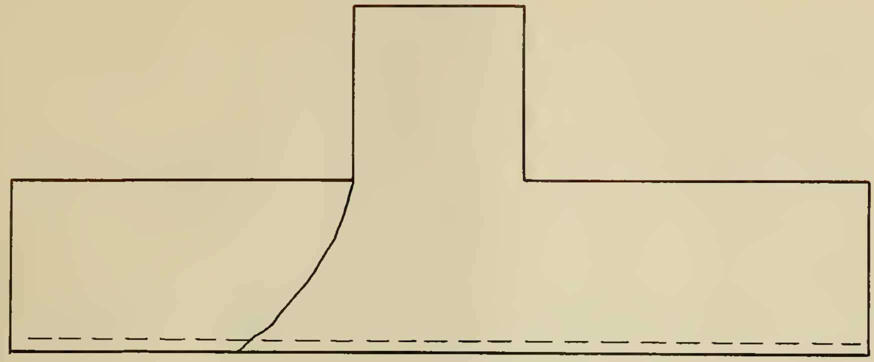

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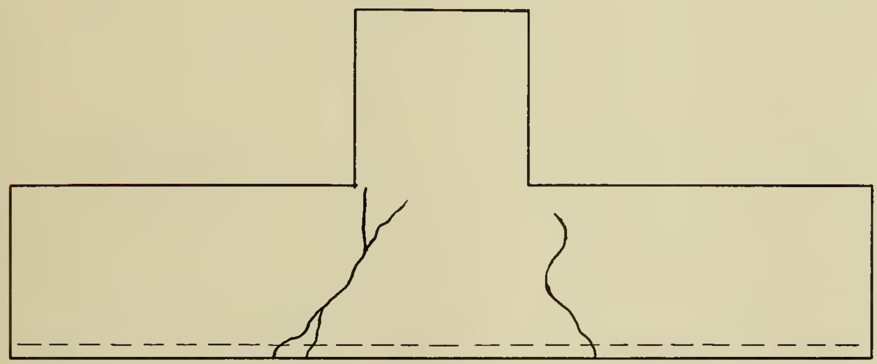

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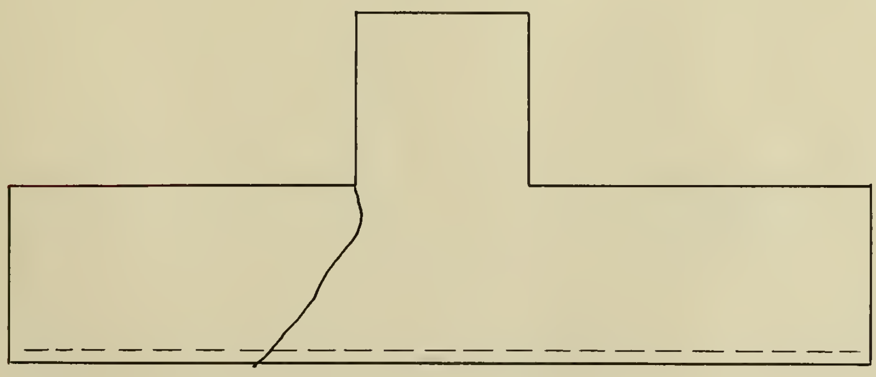

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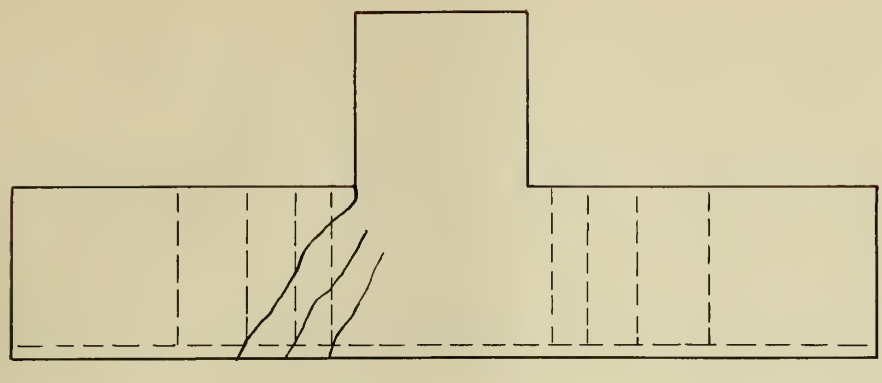

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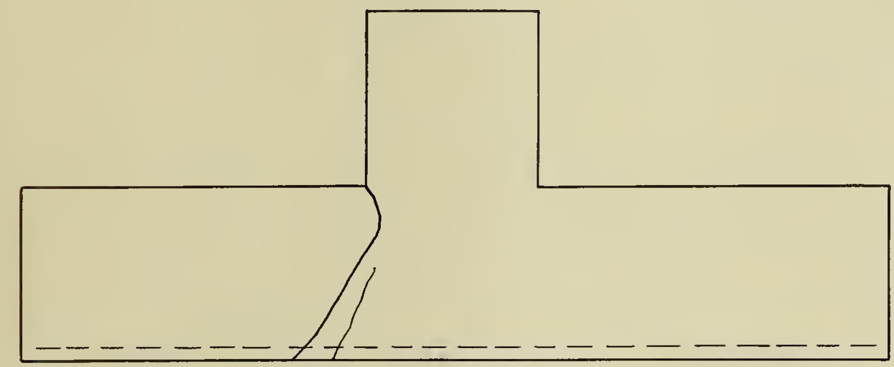

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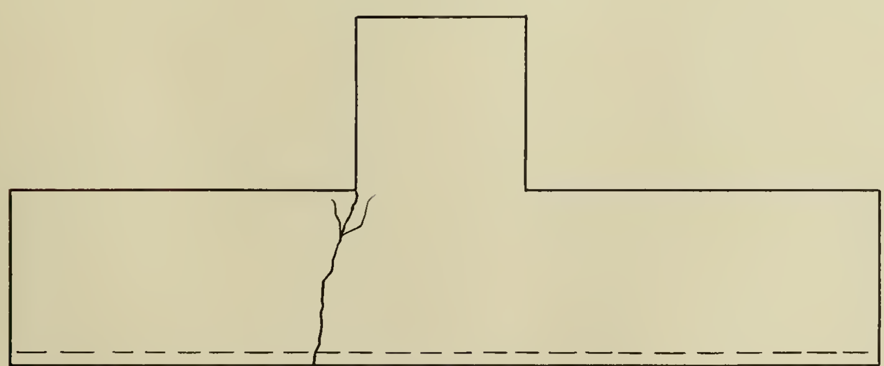

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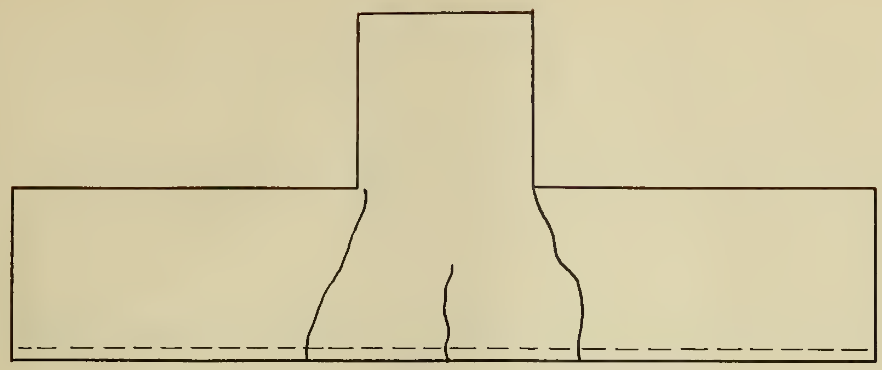

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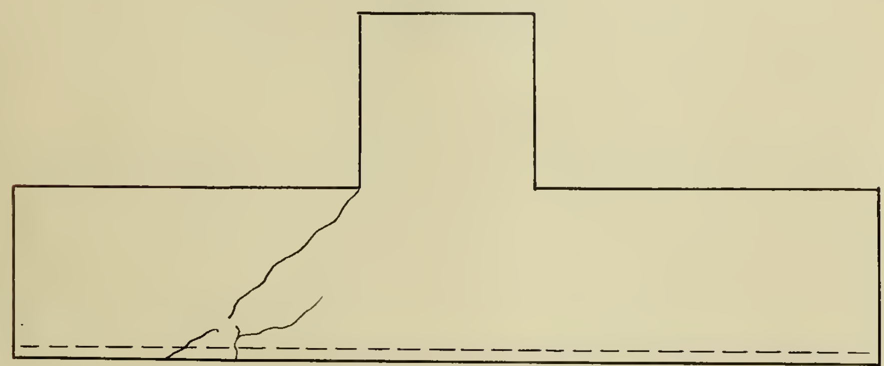

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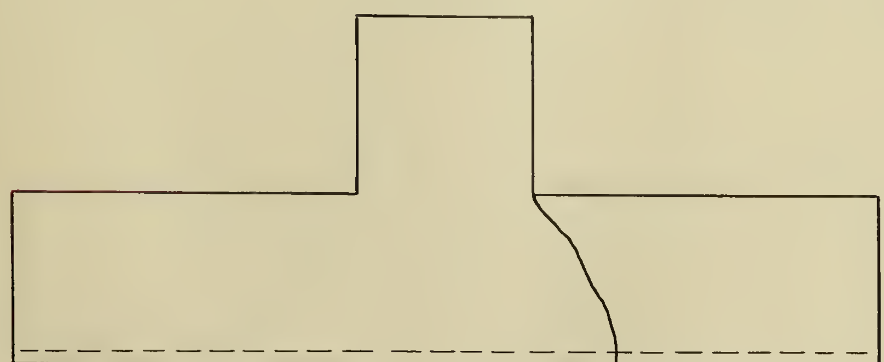

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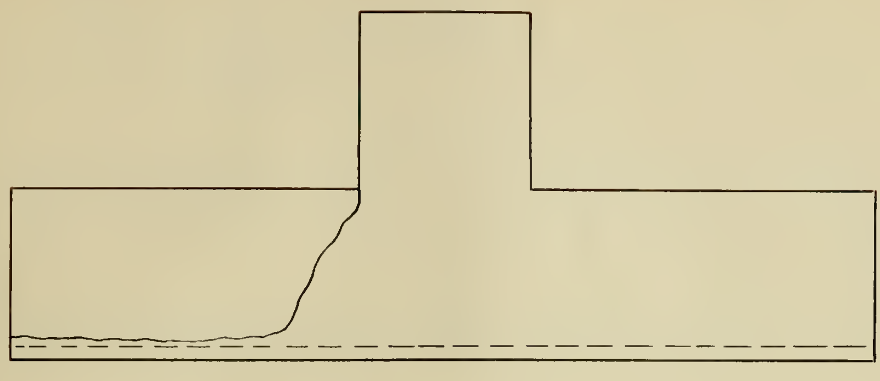

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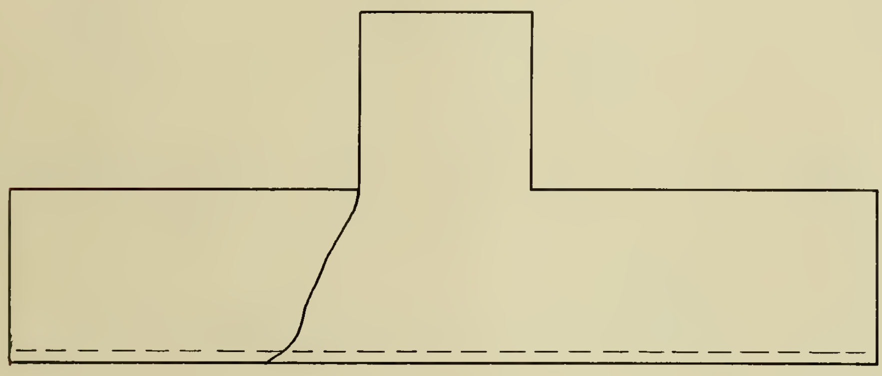

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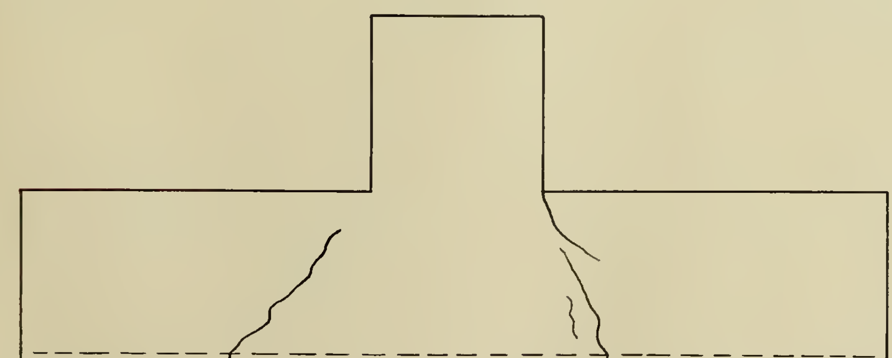

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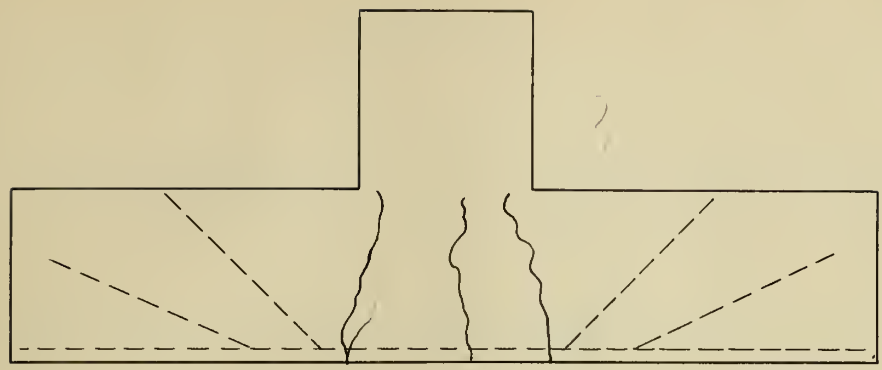

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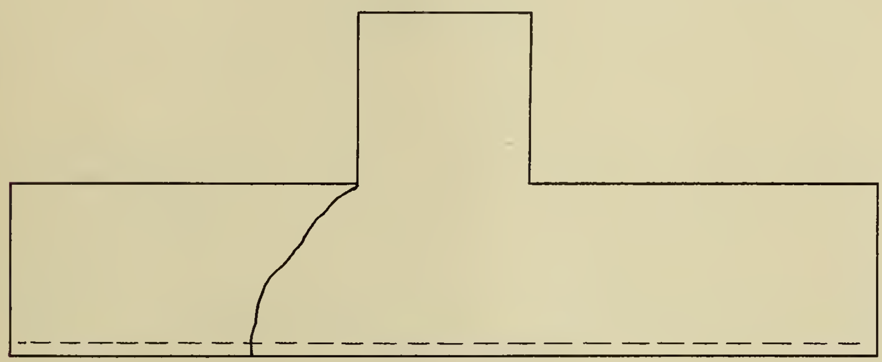

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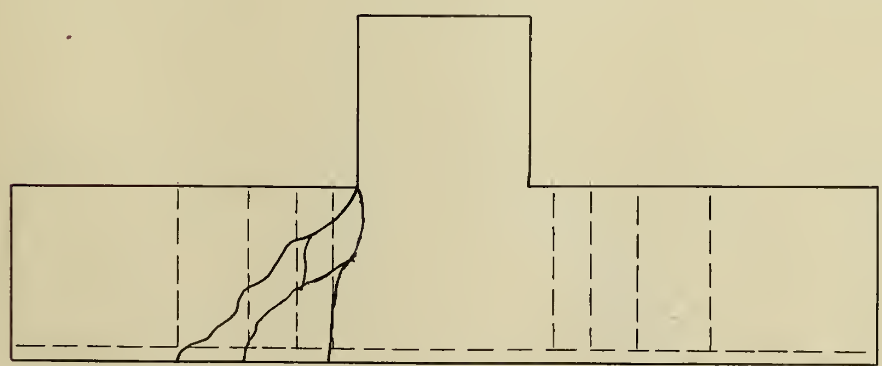

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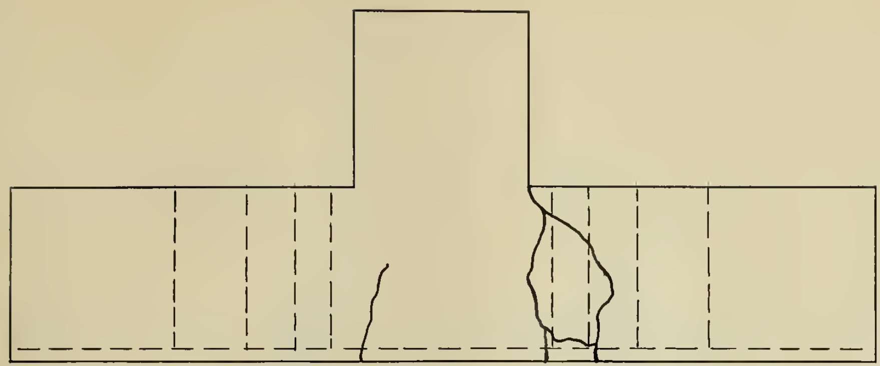

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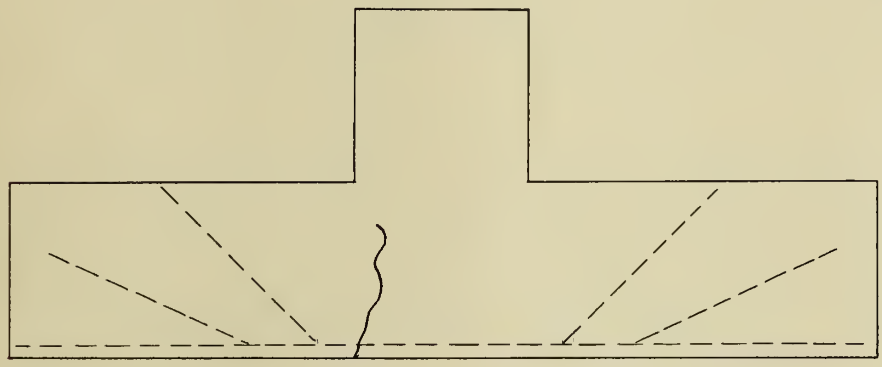

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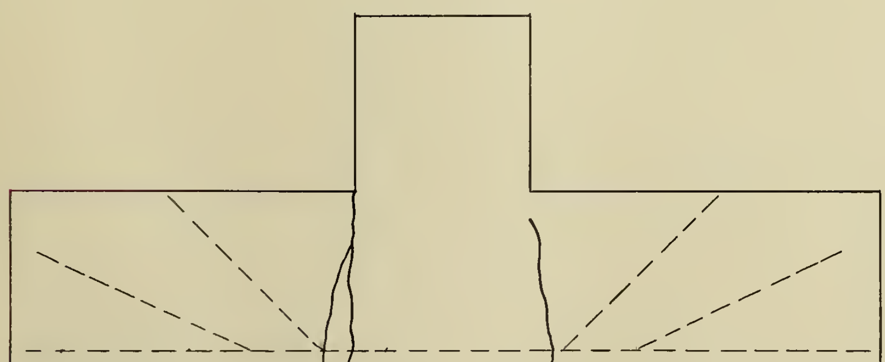

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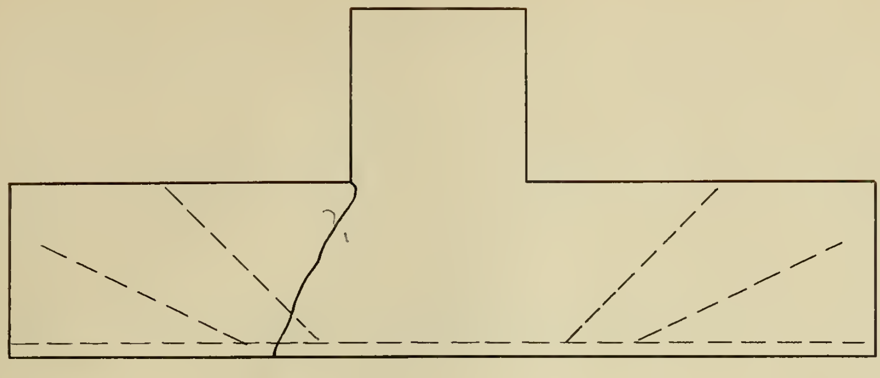

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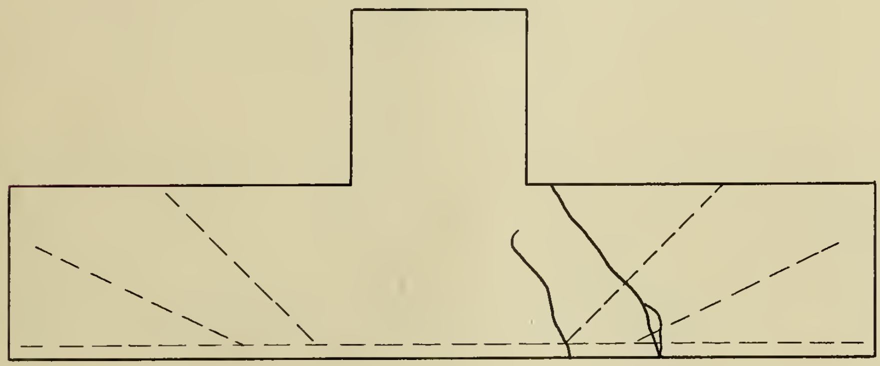

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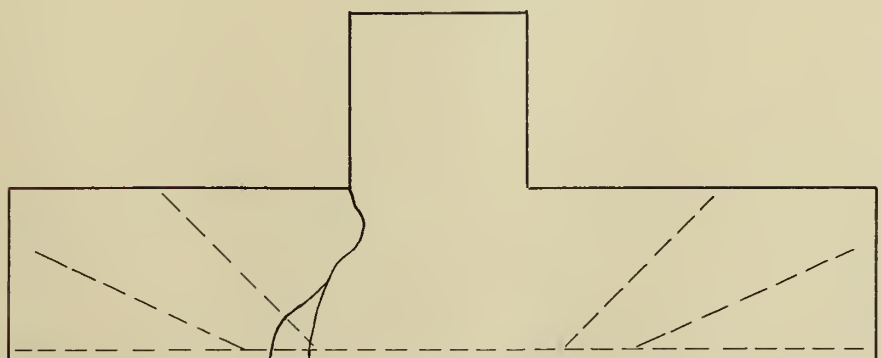

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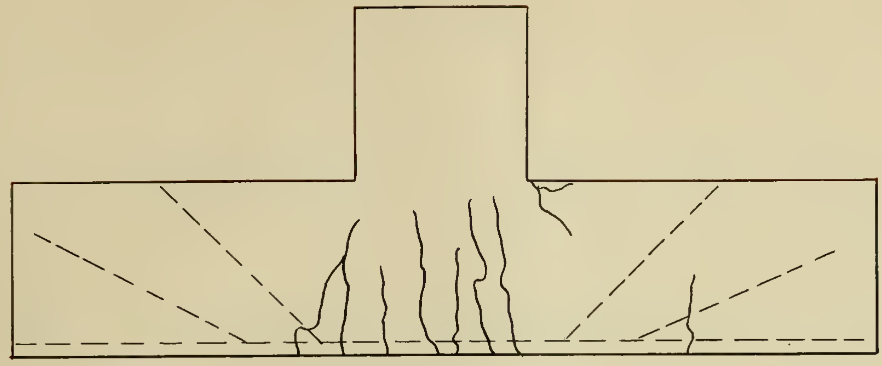

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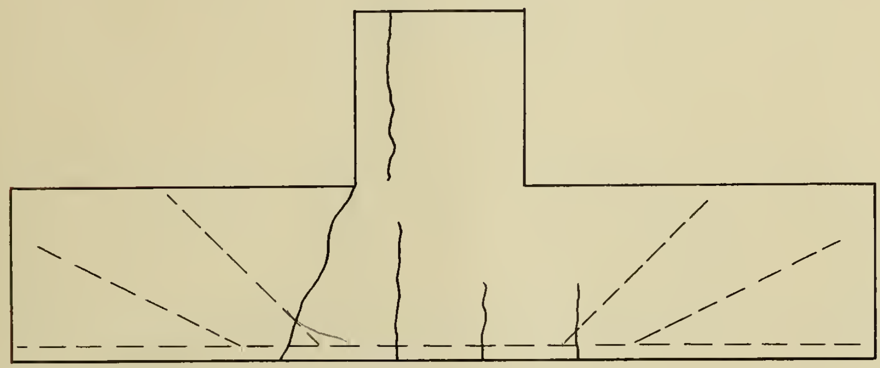

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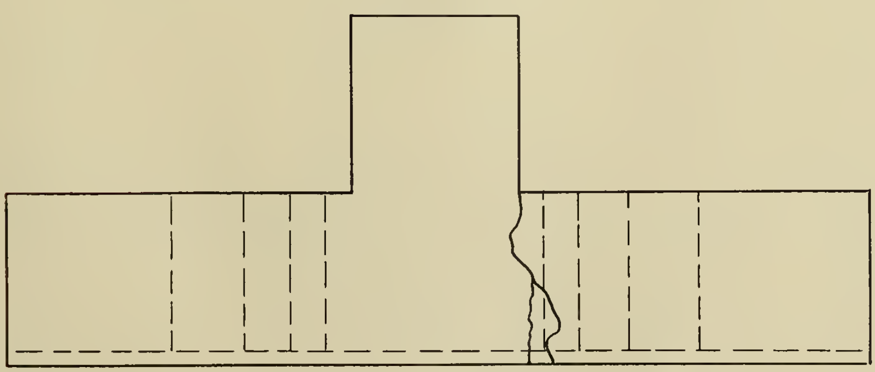

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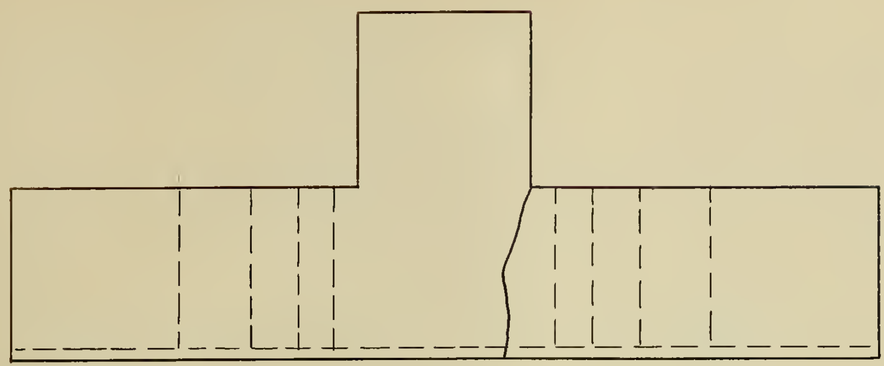

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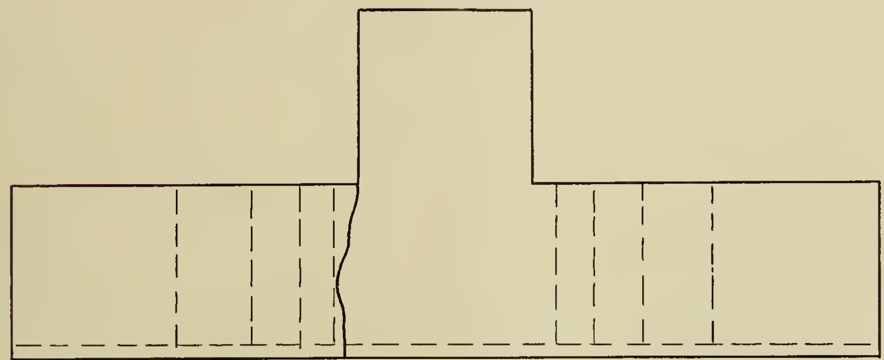

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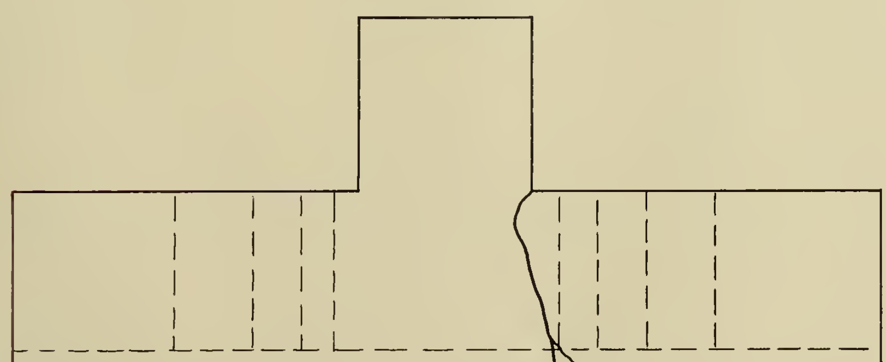

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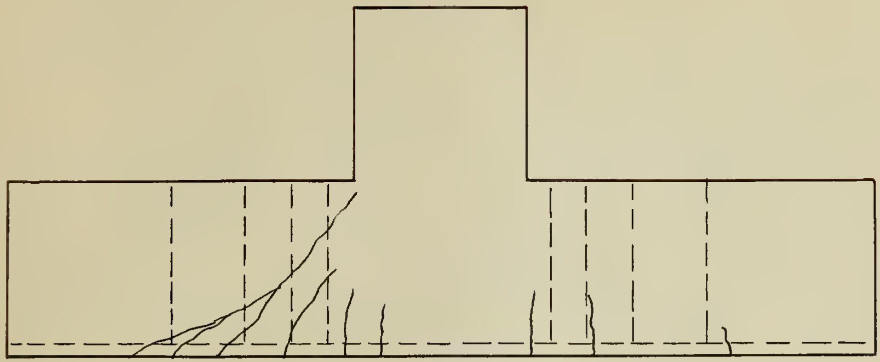

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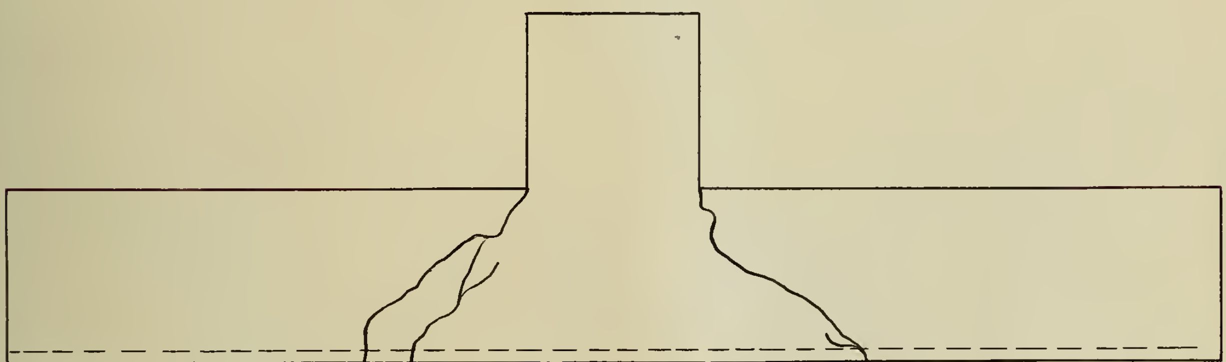

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